Irradiation Control of Insect Pests of Dried Fruits and Walnuts

The search for nonchemical commodity treatments has caused processors of dried fruits and walnuts to consider irradiation as an alternative

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Methyl bromide, a widely used fumigant for stored-product insect control, has been identified as an ozone depleter by the Montreal Protocol (UNEP, 1992). The resulting phaseout of this fumigant has encouraged food processors to place more emphasis on alternative methods. Irradiation is one potential alternative for dried fruit and nuts. Domestic applications to disinfest newly harvested product or control storage insects, as well as quarantine treatments for exported product, have been considered.

In general, irradiation uses electromagnetic radiation of energy levels sufficient to cause disinfestation of treated product without causing induced radioactivity. It is rapid and efficacious and leaves no product residue. Ionizing radiation for use in food processing is produced by radioactive isotopes, machine-generated x-rays, or electron accelerators. The source used most commonly in food irradiation is cobalt^{60}. Cesium^{137} and x-ray irradiators have also been used to treat food, although electron accelerators may be a more likely alternative to cobalt^{60}.

Dried fruit and nut processors in the United States are using phosphine fumigation as a replacement for methyl bromide wherever it is logistically and economically feasible. New fumigants, such as sulfuryl fluoride, methyl iodide, and carbonyl sulfide, may also prove useful. If so, radiation is unlikely to be used as a general alternative. However, should fumigant use become more regulated or pests develop resistance, other alternatives, including irradiation, may be considered. In other countries, and for applications such as packaged products or quarantine treatments where phosphine will not be acceptable, irradiation could provide reliable pest control and reduce methyl bromide emissions.

Scope of the Problem

Worldwide, approximately 1.2 million metric tons of raisins and prunes and 574,000 metric tons of walnuts (UNEP, 1994) are produced each year. The U.S. is the largest single producer of dried fruits and walnuts, annually producing more than 750,000 metric tons worth more than $700 million (USDA, 1997). Most of this production is centered in California. Significant production of raisins and prunes also occurs in Chile, France, Australia, Greece, Mexico, South Africa, and Turkey. Several thousand tons of dried figs and dates are produced in Middle Eastern and Mediterranean countries. Walnut production is roughly the same in China and the U.S., with these two countries accounting for about 75% of the world's production (USDA, 1997). Other countries with significant walnut production are Chile, France, India, Italy, and Turkey.

Postharvest insects cause losses to dried fruit and walnut processors through direct damage and product contamination and by creating favorable conditions for mold growth and product degradation. In the case of walnuts, infestation by quarantined insects may also hinder international trade. Although it is difficult to accurately estimate industry-wide costs from insect-related product loss and control measures, they amount to millions of dollars each year in the U.S. alone. Currently, processors use fumigants to disinfest large volumes of incoming product during harvest, as well as to control storage infestations. Methyl bromide has the advantages of rapid treatment times, relative ease of use, and low cost. For an alternative to be immediately acceptable to industry, it should have all of the above qualities.

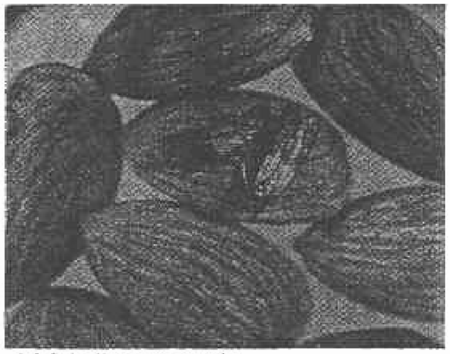
Efficacy of Radiation Against Insects

Extensive work has been done on the general effects of ionizing radiation on insects (Tilton and Brower, 1983). Insect response to radiation depends on the applied dose and the insect stage and species being treated. Undifferentiated, mitotically active tissues are most sensitive to ionizing radiation. Consequently, eggs are normally the most susceptible life stage, and adults are the most tolerant. Because insect gonads and midgut, both containing mitotically active tissues, are highly susceptible to radiation damage, irradiated insects are often sterile and stop feeding soon after treatment. Irradiated larvae may delay development, and may not die until they approach their next molt, resulting in insects surviving for some time after treatment. The high doses needed to cause immediate death of all insect stages are rarely practical because product quality suffers. For this reason, radiation treatments are designed to reduce product damage by inhibiting insect feeding and development and preventing pest population growth by sterilizing adults.

Most insects responsible for significant postharvest losses in dried fruits and nuts can be separated into those attacking product in the field and those attacking product in storage. Although most field pests do not continue to reproduce in storage, they must be controlled in raw product coming into processing plants to prevent additional feeding damage. A few field pests may have quarantine significance, requiring specific treatment of the product before export. The most serious pests are storage pests; their populations are capable of continual increase, and they are most likely to be discovered by consumers.

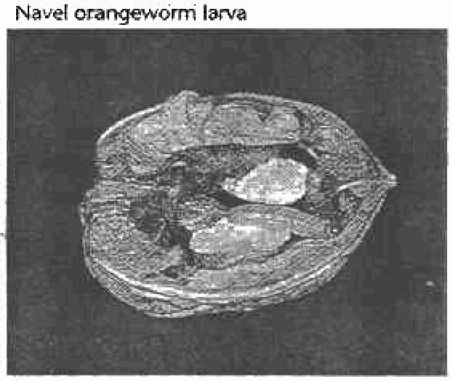
The major pests of postharvest dried fruits, walnuts, and other commodities—the Indianmeal moth *(Plodia interpunctella)* and the closely related almond moth (*Cadra cautella*)—infest product in storage. Generally, minimal dosages of 200–250 Gy have been suggested to prevent population development (Brower and Tilton, 1970, 1972; Ahmed, 1981), although to reduce post-treatment longevity a dose of 300 Gy may be more practical (Johnson and Vail, 1987; Ahmed, 1981). This dose will not completely prevent feeding of late-stage Indianmeal moth larvae (Johnson and Vail, 1988), but it does reduce product damage (Johnson and Vail, 1989). Wahid et al. (1987) found that 250 Gy was insufficient to prevent development of almond moth populations in figs, unless coupled with post-treatment storage at 20°C.

Nitidulid beetles in the genus *Carpophilus* are common field pests of drying



Adult Indianmeal moths

Navel orangeworm larva



Coding moth larva in walnut

Photos courtesy of USDA/ARS

fruits, and may cause problems in storage situations. Papadopoulou (1964) used high doses (1.0–1.5 kGy) to obtain immediate mortality in larvae and adult driedfruit beetle, *Carpophilus hemipterus*. Brower et al. (1973) prevented adult development from eggs and larvae of the corn sap beetle, *Carpophilus dimidiatus*, with doses as low as 50 Gy. Johnson (1987) found that *C. hemipterus* was controlled readily with radiation doses of 300 Gy.

The sawtoothed grain beetle (*Oryzaephilus surinamensis*) often attacks dried fruits in storage, and can be a severe problem in stored raisins. Brower and Tilton (1970, 1972) found that a dose of 200 Gy prevented production of a second generation. Papadopoulou (1964) obtained quick control of both larvae and adults of *O. surinamensis* with 150 Gy.

Infestations of walnuts by navel orangeworm (*Amyelois transitella*) and the codling moth (*Cydia pomonella*) originate in the field and are carried into storage. Navel orangeworm is also found in figs and occasionally raisins. In California, newly harvested walnuts are fumigated to prevent further damage by feeding navel orangeworm larvae. An additional fumigation is required as a quarantine treatment against codling moth for walnuts going to Japan. Husseiny and Madsen (1964) found that dosages of 300 Gy applied to navel orangeworm eggs or larvae prevented emergence of viable adults, but that 500 Gy applied to pupae was needed to obtain sterile adults. Johnson and Vail (1988, 1989) showed that feeding and damage caused by navel orangeworm larvae could be reduced by as much as 78% with dosages of 300 Gy.

Research on use of radiation against codling moth has concentrated on the development of quarantine treatments. Burditt and Moffitt (1985) showed that nondiapausing codling moth larvae were more tolerant than diapausing larvae, and recommended a dose of 145 Gy as an adequate quarantine treatment for apples. Burditt (1986) determined that 156 Gy prevented emergence of normal adults from nondiapausing larvae in walnuts. A dose of 230 Gy was necessary to completely prevent emergence of adults.

Because of prolonged survival of insects after radiation treatment, a major consideration for its use as a quarantine treatment is the possibility of live insects being found during inspections by the importing country. Currently, there is no simple method to determine that an insect has been irradiated. This issue is being addressed and must be resolved to make quarantine irradiation treatments viable. It should also be of concern for domestic treatment if it increases the chance of the consumer's finding a live insect.

Effects on Food Quality

Taste panel studies on irradiated raisins and prunes after accelerated storage (Rhodes, 1986) found that doses of up to 900 Gy did not cause deterioration in quality, but some results were inconsistent. Wahid et al. (1987) found that a dose of 250 Gy had no significant effect on taste of dried fruits even after 12 mo of storage. They also found that radiation significantly reduced ascorbic acid levels in dried fruits, but noted that these changes were not necessarily of any nutritional significance.

Auda and Al-Wandawi (1980) noted that very high radiation doses (1–10 kGy) caused some significant amino acid

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losses in dates, but the losses were greatly reduced when the dates were stored at 0°C. However, dates are not usually a valuable source of amino acid in most diets. Khan et al. (1985) found that radiation generally had little effect on total acidity, color, or sugar levels for several dried fruits, but that higher doses (0.5 and 1.0 kGy) adversely affected ascorbic acid levels.

Commodities such as walnuts, containing high levels of unsaturated lipids, are more likely than dried fruits to suffer oxidation, resulting in increased rancidity and decreased product quality. Taste panel studies reported by Rhodes (1986) found that radiation doses of up to 900 Gy did not cause immediate deterioration in quality of walnuts, but that, with storage, some quality damage occurred at 600 and 900 Gy. Rhodes (1986) recommended that walnuts be irradiated at less than 600 Gy, preferably 300–450 Gy.

Jan et al. (1988) evaluated changes in lipids in walnuts irradiated at doses of 0.5 and 10 kGy and found no radiation-induced change directly after treatment or after storage. Khan et al. (1981) noted that doses of up to 1 kGy had no adverse effect on several food items, including walnuts. Wilson-Kakashita et al. (1995) irradiated walnuts at 5–20 kGy and found no change in free fatty acids, iodine values, or 2-thiobarbituric acid levels immediately after treatment, but noted that peroxide levels were much higher.

Given the conflicting results presented above, additional work at the pilot-scale level should be done to evaluate product quality under industry standard storage conditions and durations, using local consumer taste panels.

Practical Application

California processors of dried fruits and walnuts normally fumigate all incoming product to remove field pests. They may fumigate product several additional times during storage to control postharvest insects. Packaged product may also be treated just before release to distributors as a precautionary measure. For walnuts infested with codling moth or navel orangeworm, fumigation as a phytosanitary or quarantine treatment may be required, with the severity of the treatment depending on the requirements of the importing country.

Product handling methods will dictate how easily and for which applications irradiation may be used. Dried fruits arrive at the processor in large bins, and most remain in these bins throughout storage. Fumigants are applied to dried fruits, either to covered stacks of bins in fumigation chambers or to entire warehouse or processing areas. Walnuts are often stored in bulk in large silos, although they may be kept for some time in bins. Fumigants are applied to walnuts in silos, warehouse areas, or fumigation chambers.

If irradiation is being considered for disinfesting incoming product, facilities must be capable of handling all harvested product within a short period of time. Within California, product volume is considerable, and would require individual units at each processor, or one or more large, centrally located irradiators. Use of remote irradiators to disinfest incoming product is unlikely, however, because of possible reinfestation during transport. The most-cost-effective method for handling incoming product might be to treat a thin stream of product with an electron beam irradiator. This may not be practical for dried fruits, as it requires major changes in the way the product is normally handled, but is more applicable for walnuts.

Gamma irradiators provide better penetration and are more practical than electron beam units for treating dried fruit in bins. However, given the size of bins used to store dried fruit (in California, 4 ft square and 2 or 4 ft high), it is likely that a treatment dose in excess of the current 1 kGy general maximum dose allowed in the U.S. would be needed to obtain the dose necessary for pest control (0.30 kGy) throughout the bin. Temporarily removing product from storage bins for treatment would necessitate treating or cleaning the bins separately, and permanately changing to storage bins of a more appropriate size would add to the total cost of the treatment. Doses above 1 kGy may not be a problem in other countries, and may simply require applying for a special use permit within the U.S.

Use of irradiation to disinfest packaged product holds more promise. Because the amount of product to be treated would be spread over a longer period of time, smaller on-site irradiators or remote contract irradiators could be effectively used for outgoing packaged product. Irradiation also has promise for use as phytosanitary and quarantine treatments, because a single treatment of outgoing product is sufficient. Need for this treatment would be limited to product exported to certain countries, and the amount of treated product would be reduced. Here, processors would be unlikely to use on-site irradiators; units located at ports or contract irradiators would be more efficient.

Problem of Retreatment

Under the storage procedures currently used by the industry, reinfestation of the product by storage pests is likely. However, reirradiating the product poses logistical, economic, quality, and regulatory problems. Because product cannot be irradiated while in storage, retreating product would require moving the product back through the irradiator. This would be particularly difficult for walnuts stored in silos. Retreatment would be even less likely if product must be transported to and from a remote irradiator.

Given the barriers to reirradiation, improving storage facilities or combining irradiation with preventive treatments would be necessary. Temperatures ≤10°C prevent Indianmeal moth populations from developing (Johnson et al., 1995), but cold storage of dried fruit, particularly raisins, is not very common. Some processors store walnuts at temperatures below 10°C to maintain product quality, and this may make use of irradiation before storage more practical. Modified-atmosphere storage may prevent reinfestation (Soderstrom et al., 1984). In some cases, however, initiating these improvements or preventive treatments may eliminate the need for irradiation entirely.

Safety and Consumer Acceptance

To ensure that workers are not exposed to harmful radiation, all types of irradiation equipment require special building construction and product handling systems. Irradiators also require managers with appropriate training and understanding of the technology, and licensed operators. Given that about 190 commercial gamma irradiators and more than 450 commercial electron beam accelerators currently operate in more than 40 countries, including many developing countries, it would seem that these operational and safety issues are manageable.

Of more concern may be acceptance by the consumer. Within the U.S., a small but vocal number of consumer advocacy and environmental groups have expressed concern over the issue of consumer safety (Sapp, 1995). While safety concerns are unfounded, the fear of public outcry has caused the food industry to be reluctant to adopt irradiation as a processing technique. Nevertheless, irradiated produce is currently sold in about 80 stores in the U.S. Midwest. The approval of irradiation in the U.S. for red meat and a growing understanding about food safety risks may lead to more consumer and industry acceptance of irradiation.

Consumer acceptance studies indicate that the majority of consumers will eventually accept irradiated foods. Market tests of irradiated foods worldwide have all been successful, and in numerous consumer research studies, the attitudes of the majority of consumers are often positive (Marcotte, 1995). Other work indicates that acceptance increases when consumers are provided with information about specific advantages of the process (Bruhn, 1995; Resurreccion and Galvez, 1999; Lusk et al., 1999).

Economics

Irradiation equipment capable of processing large volumes of commodities such as dried fruits is capital intensive, with turnkey facility costs in the range of \$4–7 million (Leemhorst, 1993). The costs of treating dried fruit with accelerator equipment or x-rays have been calculated to be \$1.40/ton if all California commodities were irradiated at one plant, and \$5–10/ton if 5–10 facilities were built (AECL, 1996); the associated increase in handling costs was not included in the analysis. Irradiation is more expensive than fumigation, but given the high value of dried fruit, irradiation costs might not be prohibitive.

An economic analysis of the use of radiation specifically for California dried fruits and nuts was done by Rhodes (1986). Although this report is 13 years old and costs for irradiation and other treatments have changed, the work is still interesting because it compares costs of alternative methods and combination treatments. Costs for radiation varied with plant size, with per-ton estimates being lower for larger plants. Control costs using methyl bromide for walnuts, raisins, or prunes was \$0.46–1.54/ton/year, regardless of plant size. Costs of using radiation as a substitute for methyl bromide on walnuts were estimated at \$8.32–71.89/ton/year. An alternative plan combining radiation with controlled atmosphere was estimated to cost \$6.52–66.96/ton/year. Costs of radiation as a preshipment treatment for raisins and prunes (after controlled-atmosphere treatment of yard stacks and refrigeration during final processing) were estimated at \$3.15–19.93 and \$4.80-34.67/ton/year, respectively. Costs for controlled atmosphere alone were \$4.28–10.97, \$4.23–4.88, and \$3.90–4.80/ton/year for walnuts, raisins, and prunes, repectively.

Radiation equipment and commodity processing have changed since the above study. Additional analysis should be done on the basis of current commercial practices and fumigation costs, investigating options for irradiation at different stages of product storage and marketing and including scenarios for improved storage to prevent reinfestation. Comparison of radiation costs with use of phosphine should be included, as well as the use of contract irradiators.

Potential for Irradiation

When applied to dried fruits and walnuts, irradiation is a safe and effective treatment method resulting in a high-quality product without chemical residues. An additional advantage to the method is its speed of application. Fumigants typically take one or more days for complete application, and controlled-atmosphere treatments take even longer. However, the advantages of irradiation may be offset by difficulties integrating it into current industry practices. Fumigants are popular, in part because they can often be used to treat product in place, in either covered stacks, storage silos, or warehouses, making retreatment a simple matter.

It is unlikely that irradiation would ever be a complete substitute for fumigation within the dried fruit and nut industry. Given problems associated with reirradiation, its use becomes practical only when coupled with some type of protective measure designed to prevent reinfestation, such as controlled atmospheres.

Where rapid treatment is not critical, controlled atmospheres alone might be a more economical alternative for product in storage, particularly in covered stacks. When rapid treatment of relatively small amounts of product is desired, particularly of outgoing packaged product or product needing a phytosanitary treatment, irradiation may be a viable option. In both cases, contract irradiators may be the most cost effective.

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